Status of Fast Reactor Programme in India

P.R.Vasudeva Rao

Indira Gandhi Centre for Atomic Research

Kalpakkam-603 102

Workshop on Monju, 25April 2013

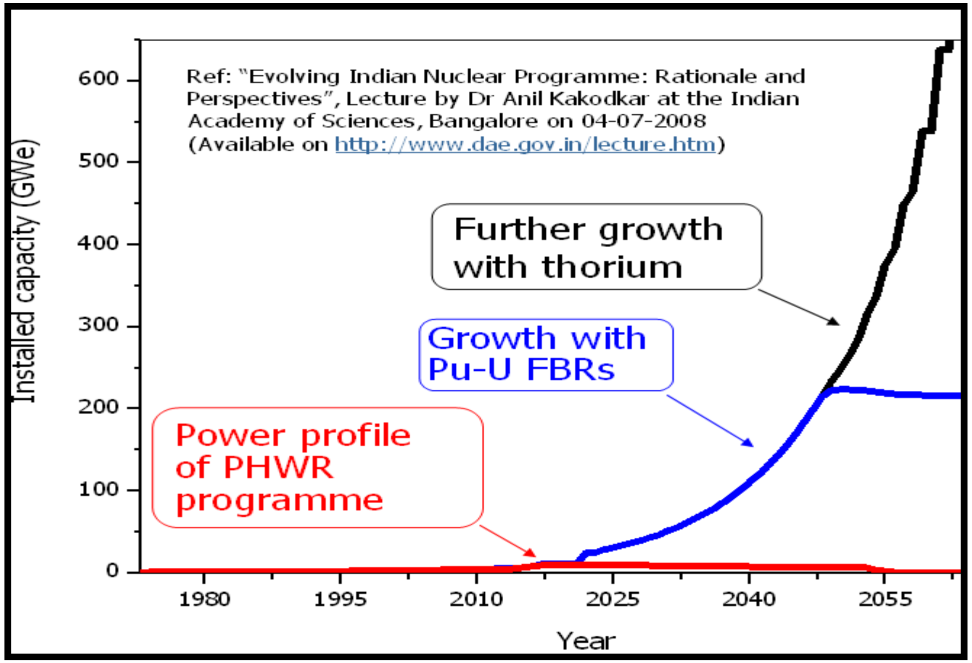
Indian Perspective on Fast Breeder Reactors

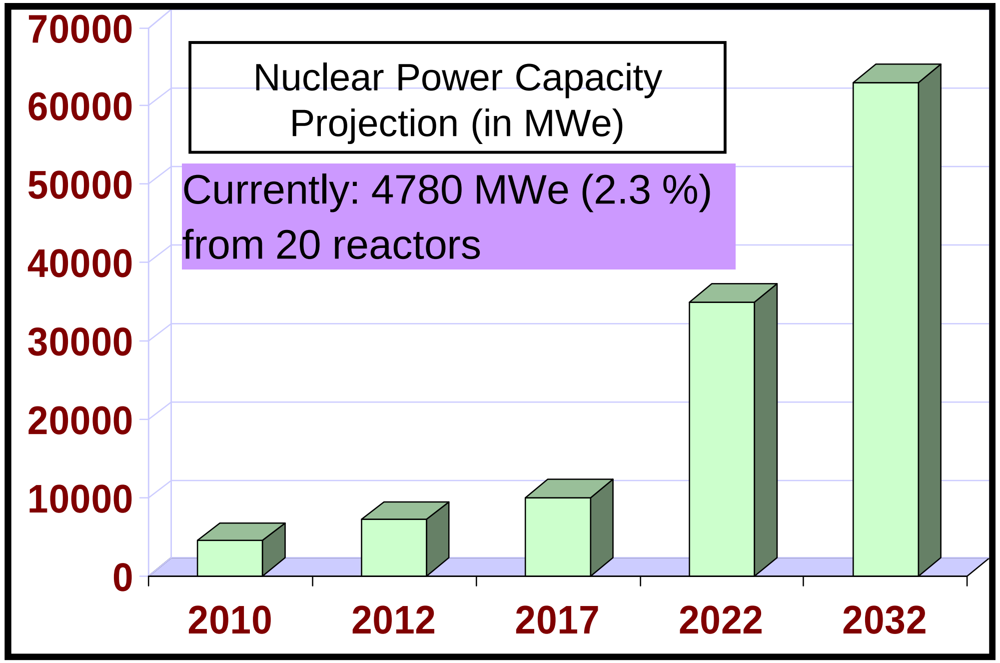
- Effective utilisation of the limited resources of natural uranium- for sustainable nuclear energy development
- Higher temperature operation, leading to higher conversion efficiency: lesser heat rejection to environment
- Breeding potential – enabling faster growth of nuclear power
- Waste management: burning of minor actinides and long lived fission products

Indian programme on fast reactors: mixed oxide fuel based FBRs for technology demonstration, with metal fuelled reactors as long term option

Uncertainties in oil prices and available uranium resources bring FBR with closed fuel cycle to focus

FBR's Role in Nuclear Contribution in India

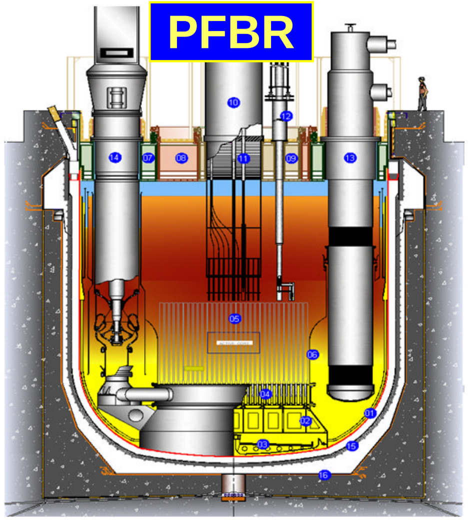




FBTR

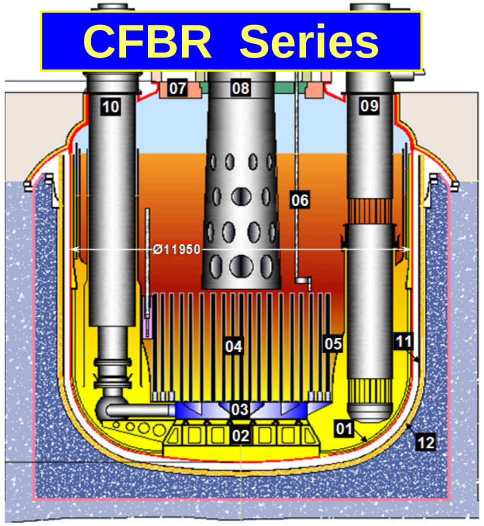
- 40 MWt (13.5 MWe)
- PuC – UC
- Since 1985…

PFBR



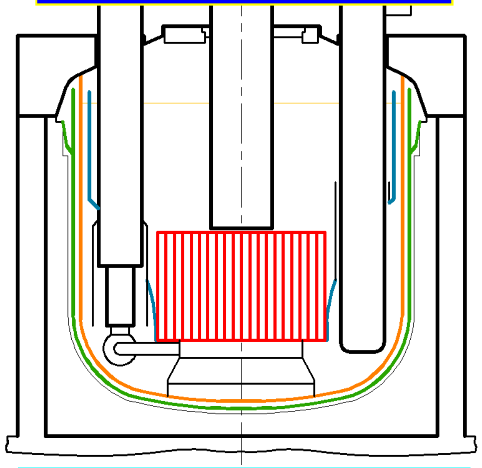
- 500 MWe
- UO2-PuO2 (MOX)
- From 2014…

CFBR Series



- 500 MWe
- UO2-PuO2 (MOX)
- From 2023…

MFBR Series



- 1000 MWe
- Metallic fuel
- Beyond 2025…

FBTR: operation summary

FBTR, in operation since 1985, is the flag-ship of IGCAR and is the test bed for fast reactor fuels and materials.

It has completed 20 irradiation campaigns . During the campaigns, the reactor has been operated to a power level of 20.3 MW, and sodium outlet temperature of 540 deg C.

Its unique carbide fuel has set an international record in burn-up (165 GWd/t). One fuel pin failure event was observed and the failed fuel subassembly was quickly detected and removed for PIE

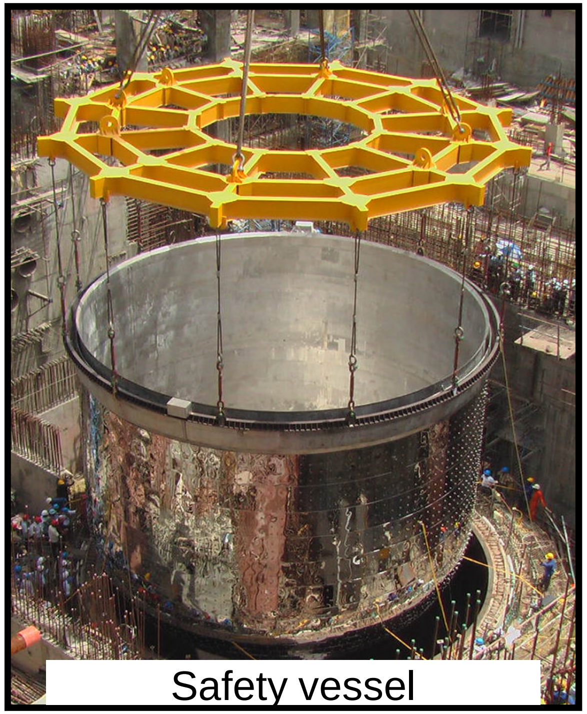
The performance of sodium systems for the past 27 years has been excellent. Sodium pumps have crossed 7, 39,000 hours of cumulative, continuous operation. Steam generators have performed without a single leak incident

PFBR test fuel irradiated in FBTR to a burn-up of 112 GWd/t and discharged for Post-irradiation Examination

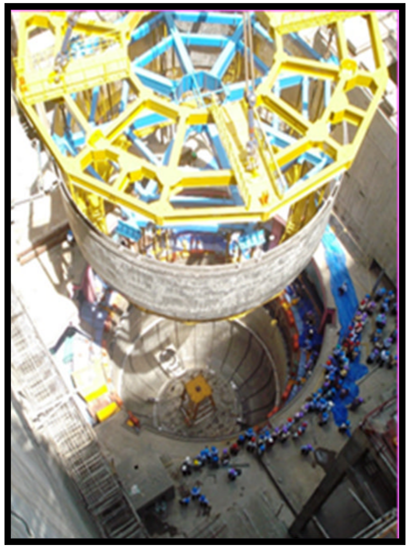
Campaign Missions of FBTR

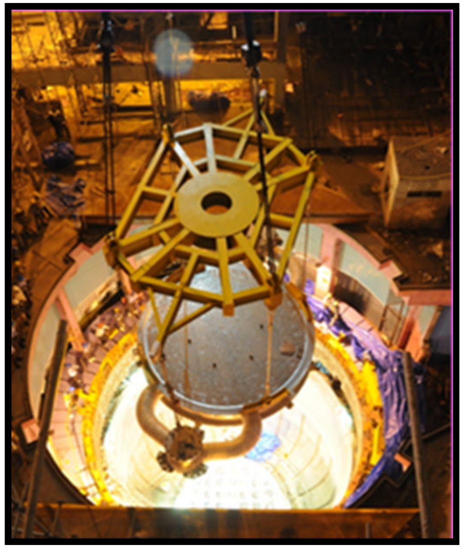
- Irradiation of sodium bonded metallic fuel test pins (Natural & enriched U-6% Zr loaded; U-Pu-Zr to be irradiated from next campaign)
- Irradiation of structural materials.
- Production of radioisotopes (currently Sr^{89})
- Irradiation of shield materials (ferroboron)
- Testing of instruments and components (eg.high temperature fission chamber (HTFC) for PFBR, Kalman filter based instrument for drop time measurement of DSRDM for PFBR)
- Training of operators (PFBR staff undergoing training)

Current Status of PFBR Project

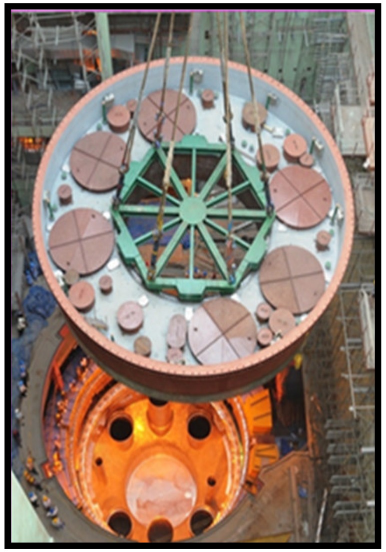

Safety vessel


Main vessel


Thermal baffles


Grid plate

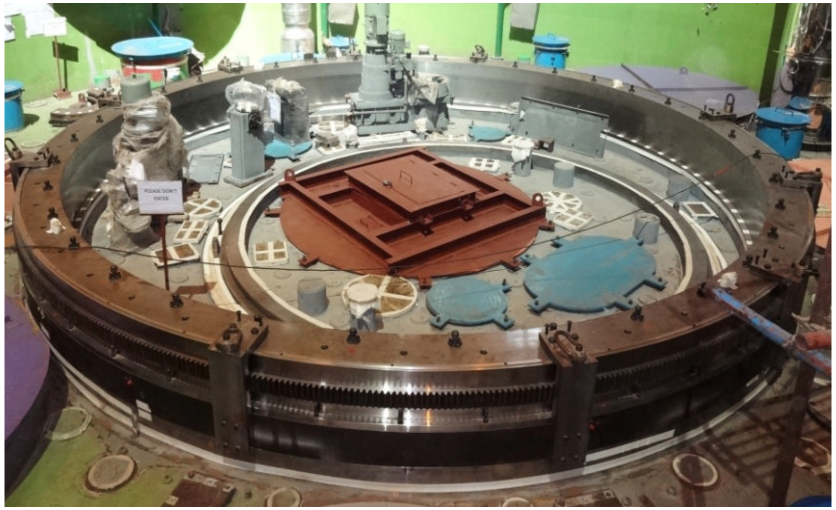

Inner vessel


Roof slab

Current Status of PFBR

- Sodium Filling by End of 2013
- Hot commissioning during first quarter of 2014
- Reactor critical in Mid 2014
- Power operation end 2014

Dummy core in core



LRP/SRP on Roof Slab

All SGs erected

Erection of sodium piping

Status of Turbo Generator

6th SG erection in SGB-2

Sodium Piping

R&D on Safety related to Sodium

Fundamental Tests in MINA:

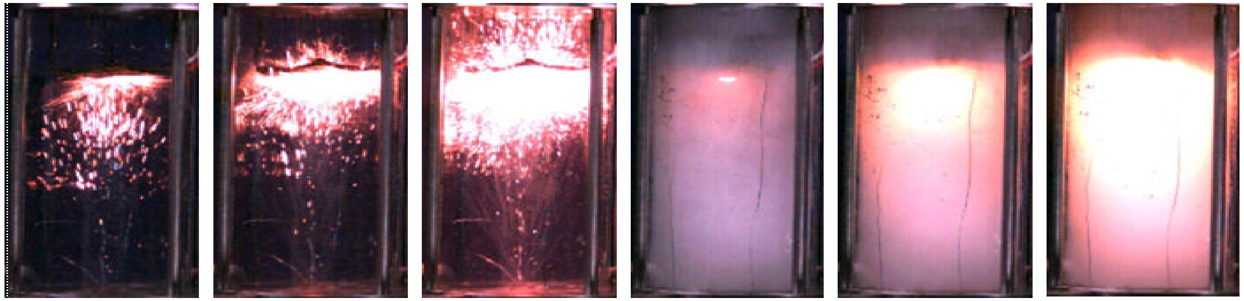
Sodium spray fire scenarios, sodium fire followed by cable fire, sodium concrete interactions, sodium water/steam reactions, qualification innovative sodium sensors and sodium fire extinguishes, etc

Medium & Large Scale Experiments (SOCA, SFEF):

Qualification of sodium leak collection trays, sodium fire scenarios to investigate the integrity of safety related components on the top shield platform

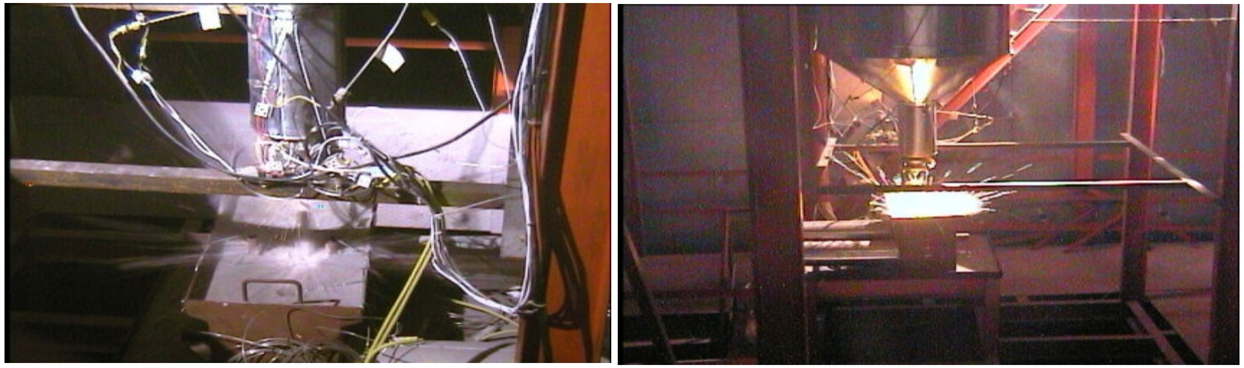
LabView Sodium School:

IGCAR-CEA Cooperation

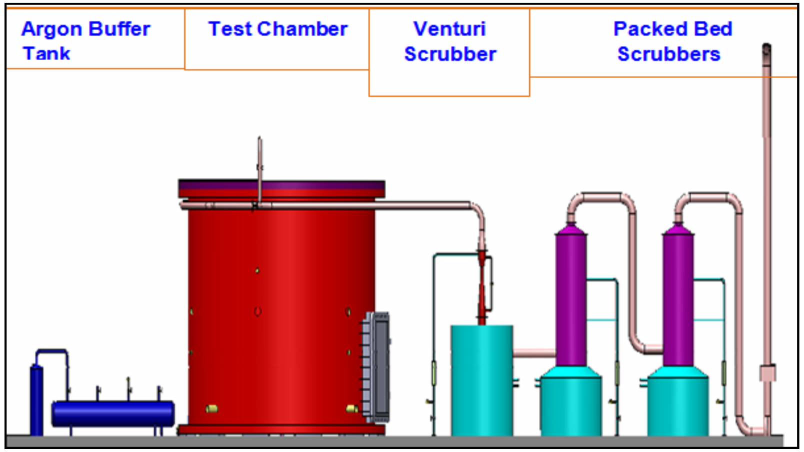


20 ms 24 ms 32 ms 7200 ms 7600 ms 8600 ms

Sodium fire **followed by** ***cable*** **fire**



Performance Evaluation of Sodium Leak Collection Tray



SOCAFacility to simulate Na fire scenario on top shield

Simulation of Severe Accident Scenario

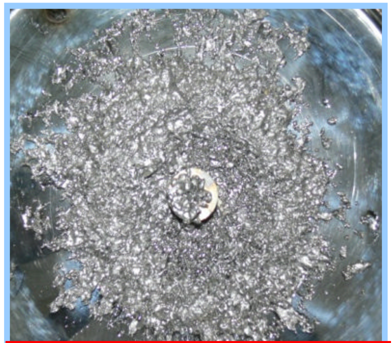
- **Mechanical consequence: Vessel deformations, integrity of SGDHR, sodium release to Reactor Containment Building**
- **Post Accident Heat Removal Scenario**
- **Molten fuel coolant interactions**
- **Core catcher performance**

Potential of main vessel: 1200 MJ

Grid plate melt-through scenario

Molten Fuel Coolant Interaction Studies

SOFI Facility



Woods metal in water

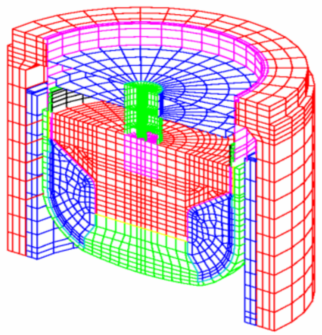
Uranium in sodium

Estimation of work potential
Characterisation of debris: (constitution, size & heat trasfer)
Dispersion on core catcher
Post accident heat transfer modes

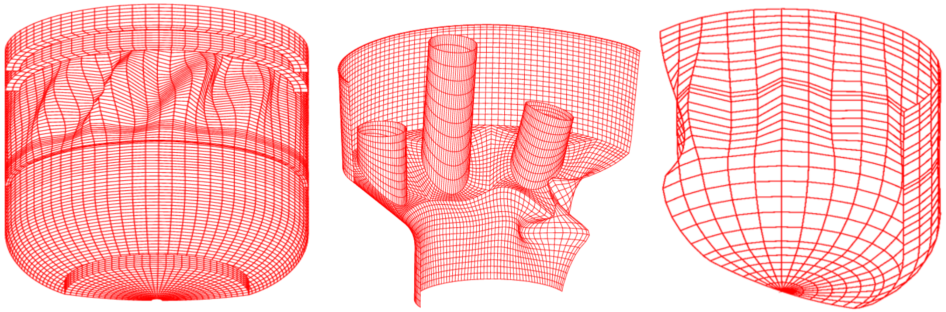
Investigations to Comply with Seismic Design Criteria

Theoretical and Experimental Investigations on:

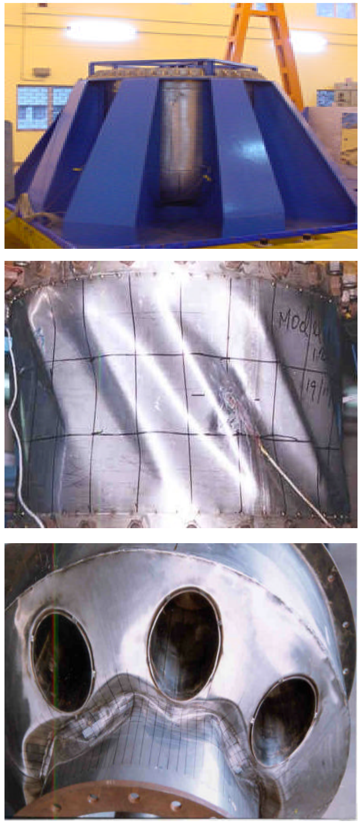
- Buckling of vessels
- Reactivity oscillations
- Pump seizure
- Performance of absorber rod drive mechanisms



3D FE model of RA

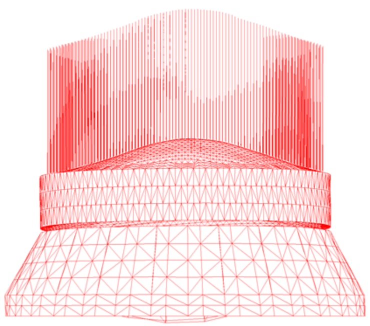


Buckled mode shapes of RA vessels under seismic loadings

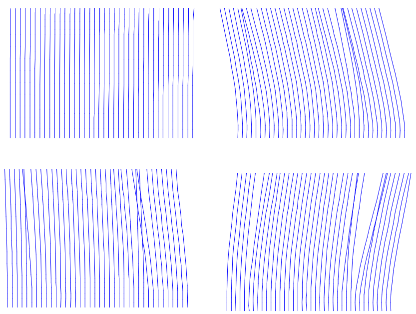


Experimental Validation

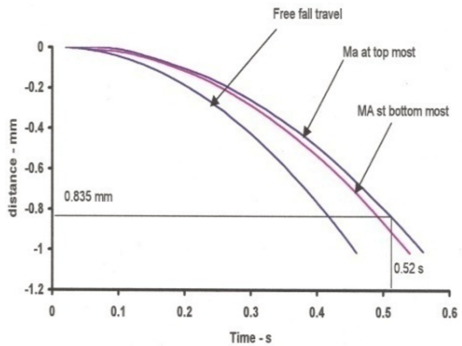
ARDM model



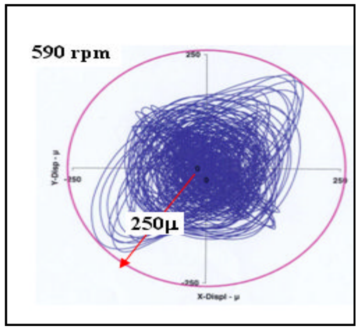
Integrated FEM model of core, GP and CSS



Dynamic displacements of core SAa



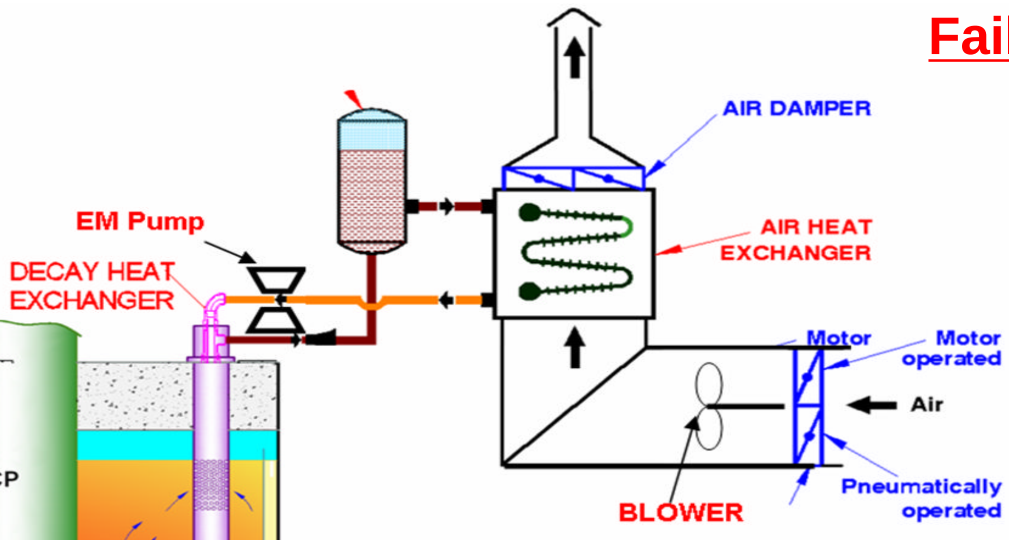
Drop time of absorber rods during SSE

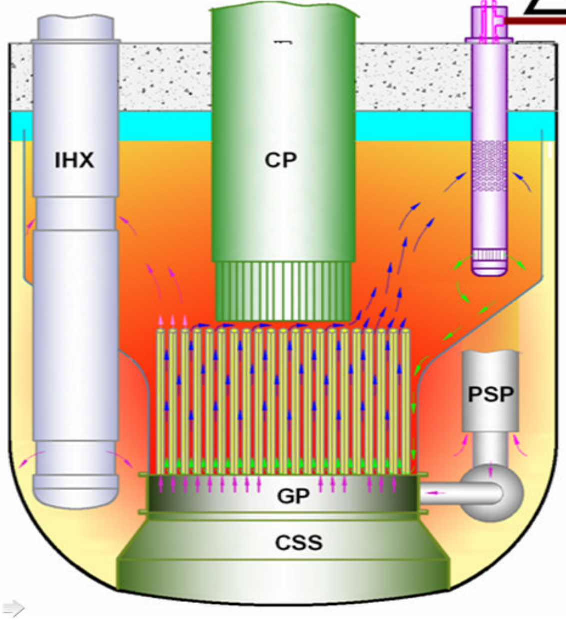


HSB orbit under SSE to ensure no impact

Pump Seizure

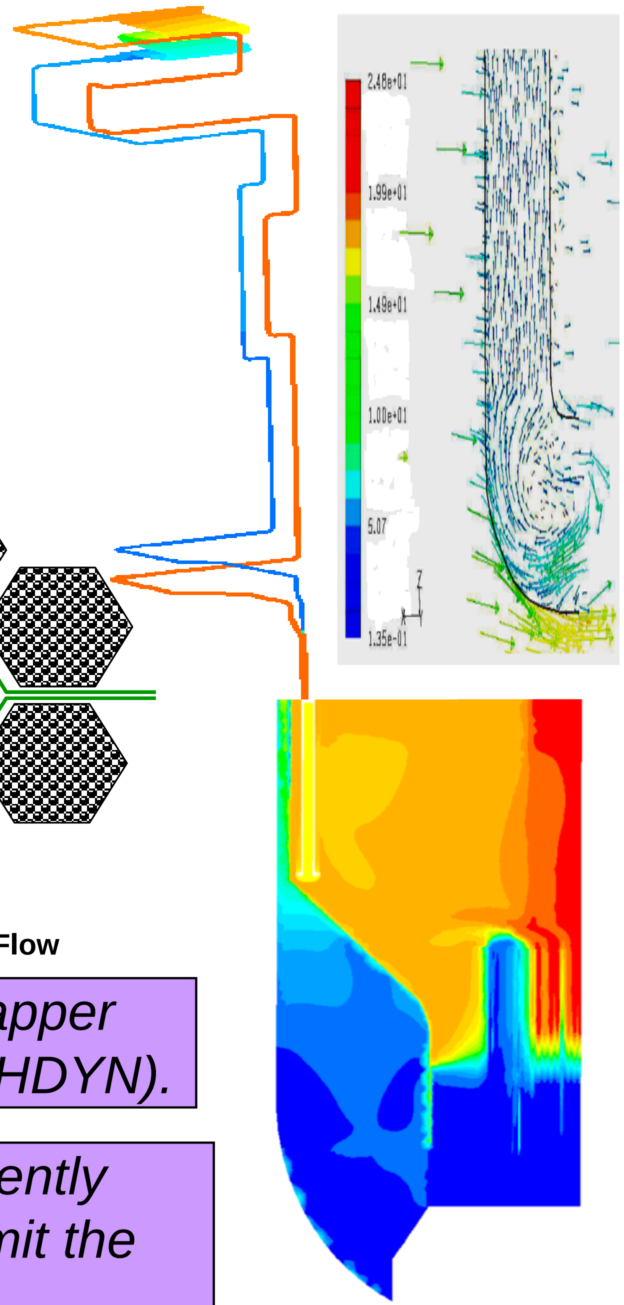
Safety Grade Decay Heat Removal System

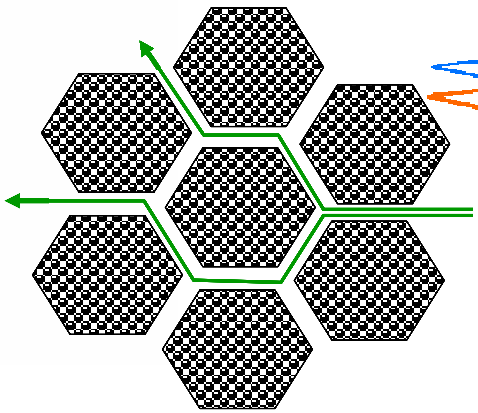




In mixed mode circuit EM pump is provided in intermediate circuit and air blower is provided in air circuit.

Failure of all Pumps





Inter Wrapper Flow

Analysis with multi-dimensional model for pools with inter-wrapper space (StarCD) and 1-D model for equipments and piping (DHDYN).

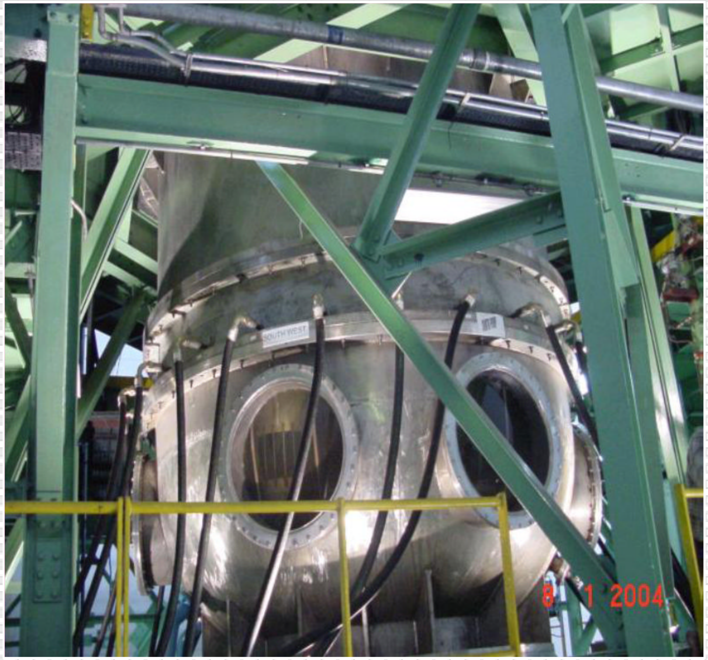
Availability of any two circuits for 7 h and one circuit subsequently with primary circuit under natural convection is sufficient to limit the temperatures below category 4 limits

Performance Evaluation of DHR Capability

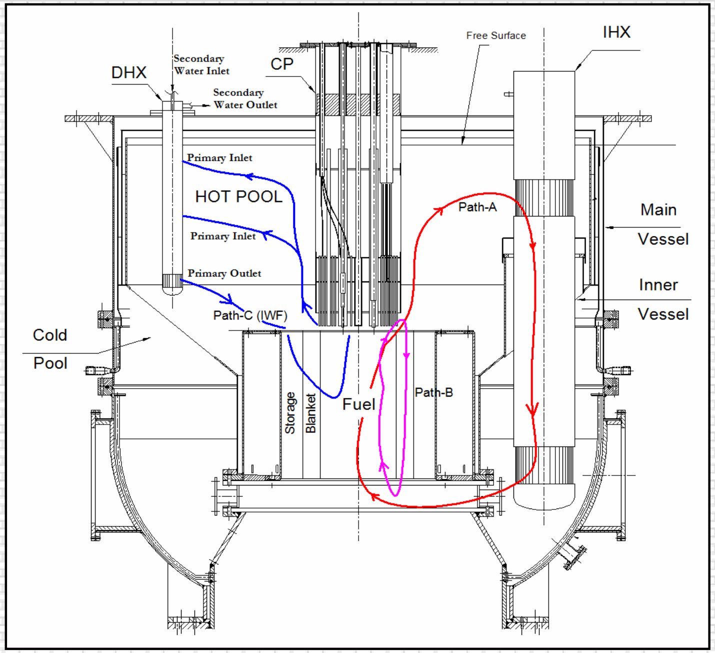
- **Temperature & flow distributions in the hot pool**
- **Confirmation of SGDHR system Performance**
- **Assessment of Inter Wrapper Flow contribution**

Facilities Utilized

FBTR, SAMRAT and SADHANA



SAMRAT Model (1/4 scale)



Natural convection flow paths

SADHANA loop

POST- FUKUSHIMA ACTIONS

- Reactor trip on seismic event
- Augmenting DG Diesel oil storage day tank capacity
- Air cooled Mobile DG set (SBO DG)
- Additional Battery Bank
- Additional water supply hook up for spent fuel storage pool
- Provision of water tight doors/shutters for Steam Generator Buildings, DG Buildings etc.
- Additional Stores
- Sealing the penetrations of cables and pipelines to NICB and Power Island to prevent water entry
- Provide alternate approach roads to Kalpakkam site
- Emergency Preparedness Plan to handle events at PFBR due to Natural calamities

Sensors for sodium systems

Electrochemical sensor for hydrogen in sodium

P_{H_2}(sample) // Electrolyte // P_{H_2}(reference)

Solid electrolyte: $CaBr_2$-CaHBr

Detection limit: ≤ 50ppb

Resolution: 10 ppb change over 50ppb background

Simple instrumentation and inexpensive

Chosen for PFBR and one sensor incorporated in Phenix reactor, France

Sensor for trace hydrogen in argon cover gas

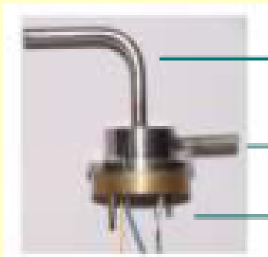
Required for steam leak detection during reactor start up and low power operation

Operation in FBTR since 12 years and chosen for PFBR

Thermal conductivity detector for detection of hydrogen

Lowest detction limit: 30 ppm H_2
(PFBR Spec.: 100ppm)

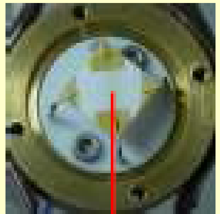
Thin film sensor for measurement < 30 ppm H_2



Gas outlet

Gas inlet

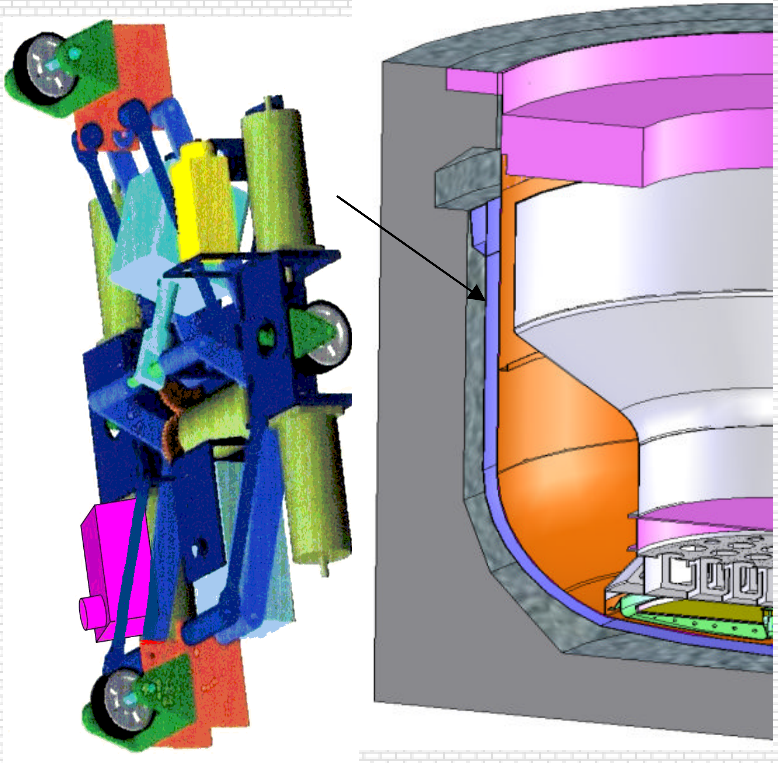
Sensor & heater leads

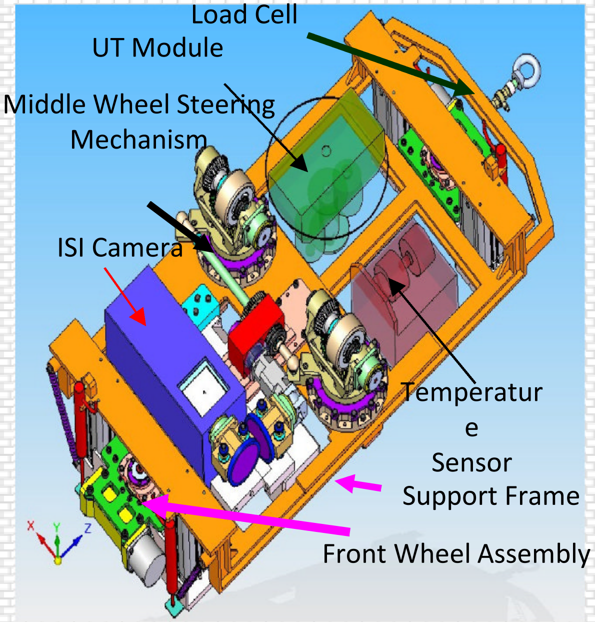


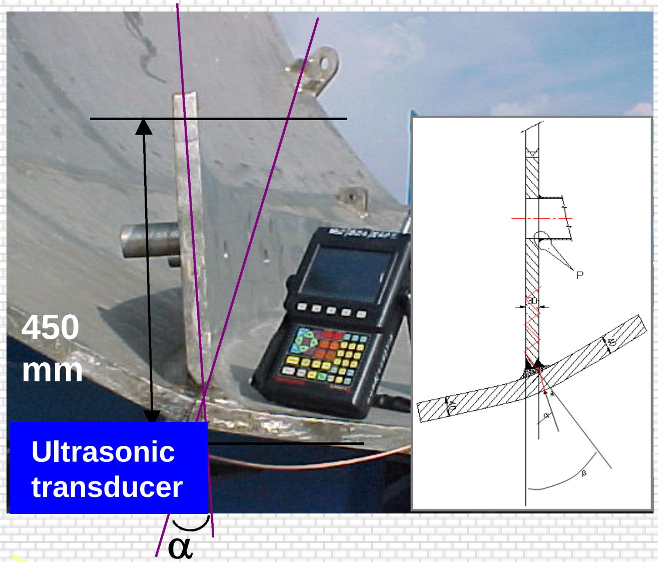
Pd doped SnO_2 thin film

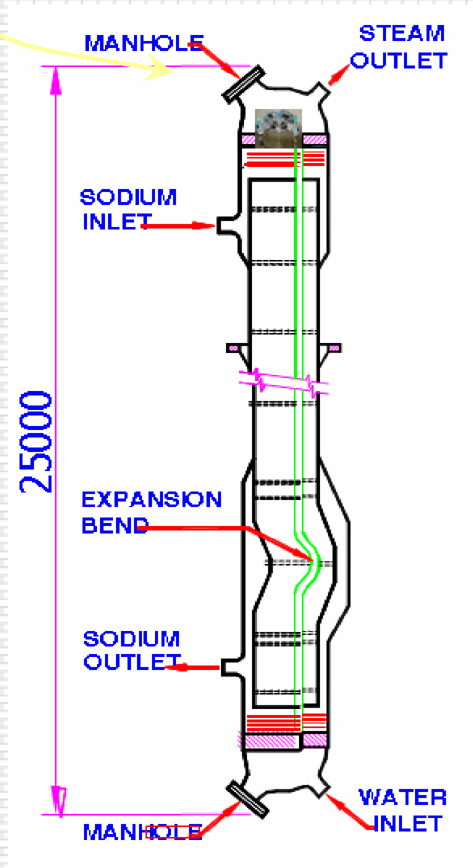
Robust Technologies for In-Service Inspection (ISI)

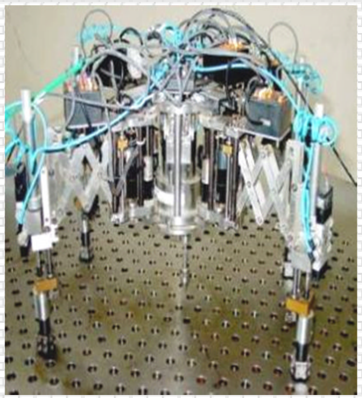
ISI of main vessel including core support structure

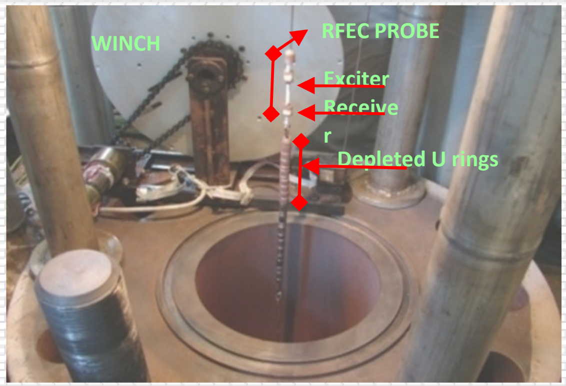






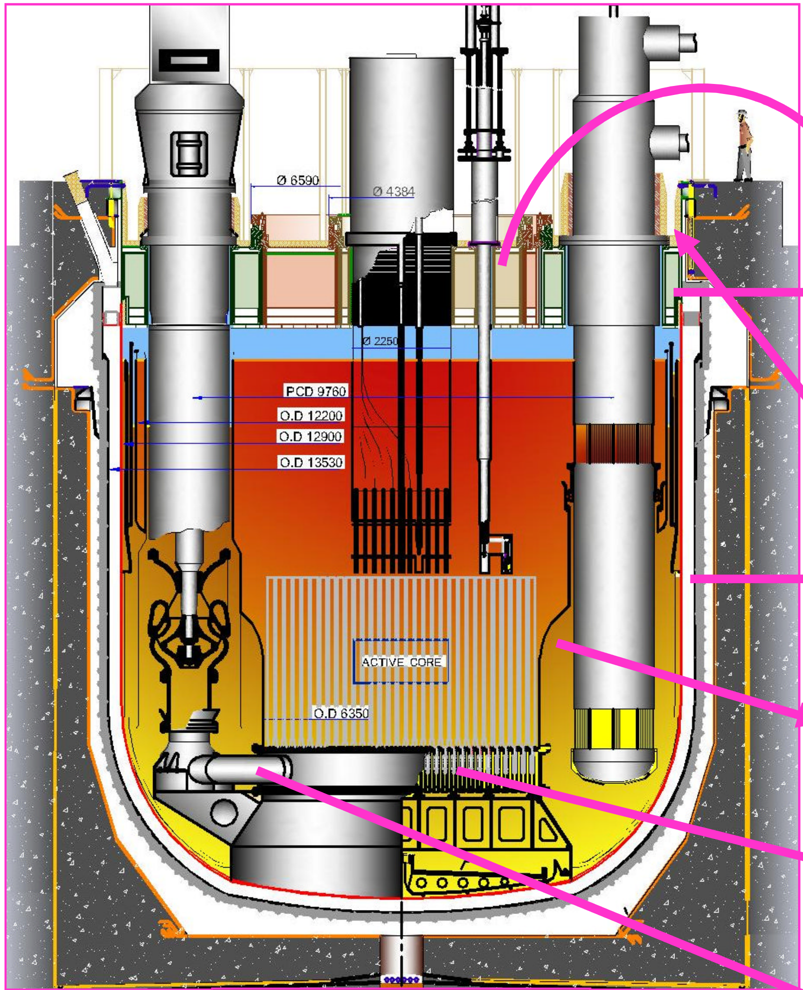






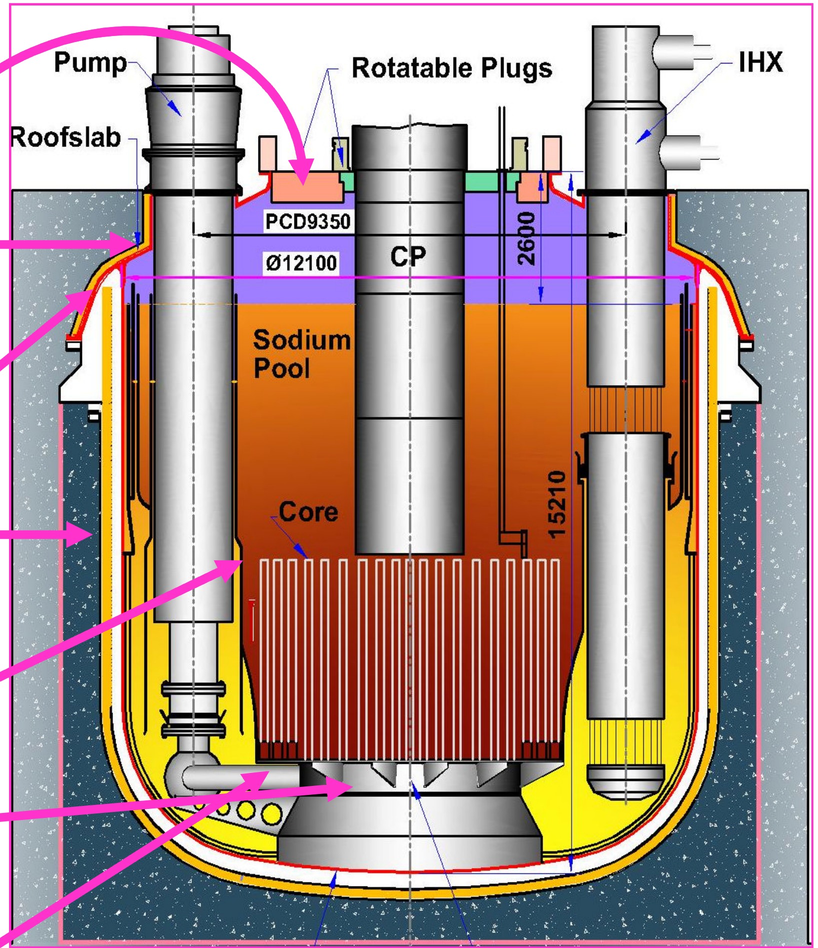
ISI of steam generators of PFBR – In-house developed Remote field eddy current testing technology

Reactor Assembly of PFBR & FBR-1



PFBR

- BOX to Thick plate Rrotatable plugs
- Box to Dome shaped Roof slab
- Support under Tension to compression
- Separate to Embedded Safety vessel
- Conical to Toroidal Inner vessel
- Bolted to Welded Grid plate
- Four to Eight Primary pipes



FBR 1&2

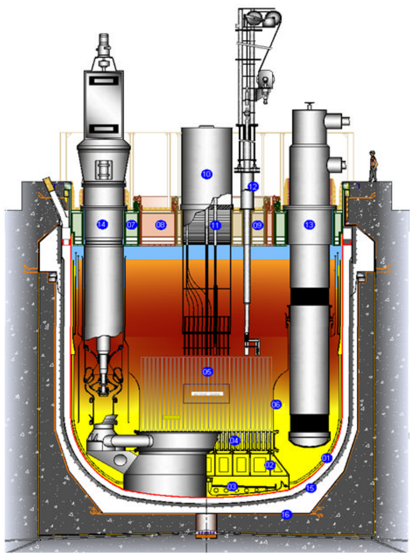
Motivation to introduce innovations

PFBR construction experience, significant saving in capital cost and reduced construction time, features to be adopted for future SFRs

Safety Features: Current & Future Directions

SGDHR - Safety Grade Decay Heat Removal
BDBA - Beyond Design Basis Accident
CDA - Core Disruptive Accident
RCB - Reactor Containment Building
SA - Subassembly
SDS - Shutdown systems

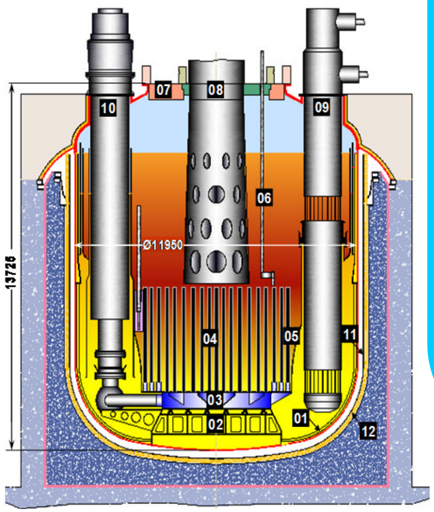
Convincing Safety features



PFBR

- Safety Criteria 1990
- Number of scrams ~800
- CDA is BDBA
- 100 MJ Energy release
- Core Catcher for 7 SA
- RCB for 25 kPa
- Decoupled 2D Analyses
- Full scale Testing of SDS
- Scaled down tests-SGDHRs
- Extensive Tests on Structural integrity under CDA
- Open Fire Sodium Tests
- CDA: 50 mSv / event
- < 350 P-mSv/ y (cumulative)

Passive safety features



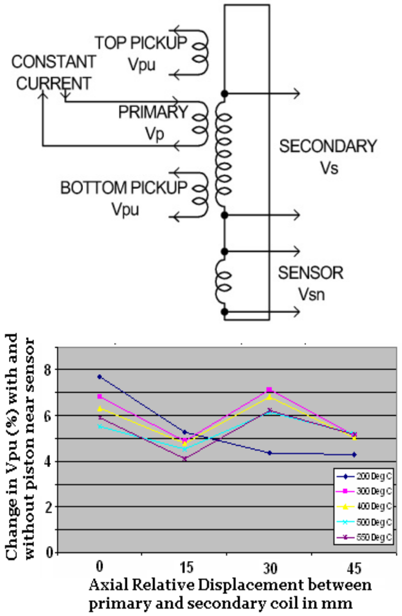
CFBR

- Safety Criteria 2011
- Number of scrams ~240*
- CDA is Residual risk*
- < 100 MJ Energy release*
- Core Catcher for whole core
- RCB for 15 kPa*
- Coupled 3D Analyses
- Full scale Testing of SDS
- PFBR data for SGDHR
- Tests on sodium Leak
- Extensive sodium fire tests
- CDA: 20 mSv / event*
- < 100 P-mSv/y (cumulative)*

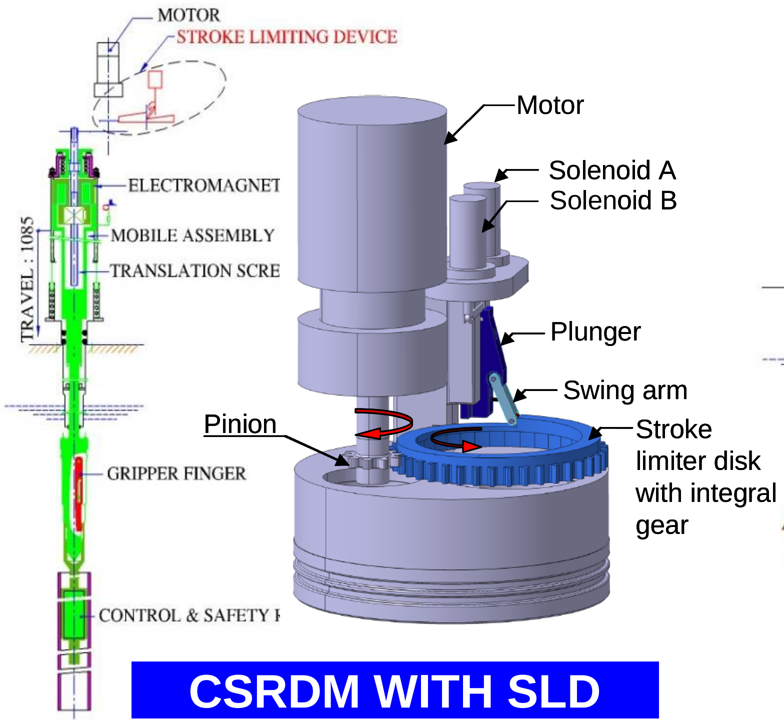
* Current study

Innovations & Collaborations

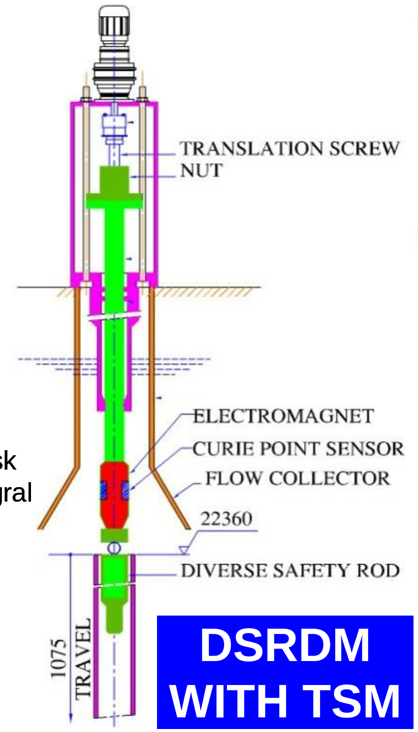
Enhancing Reliability of Shutdown System



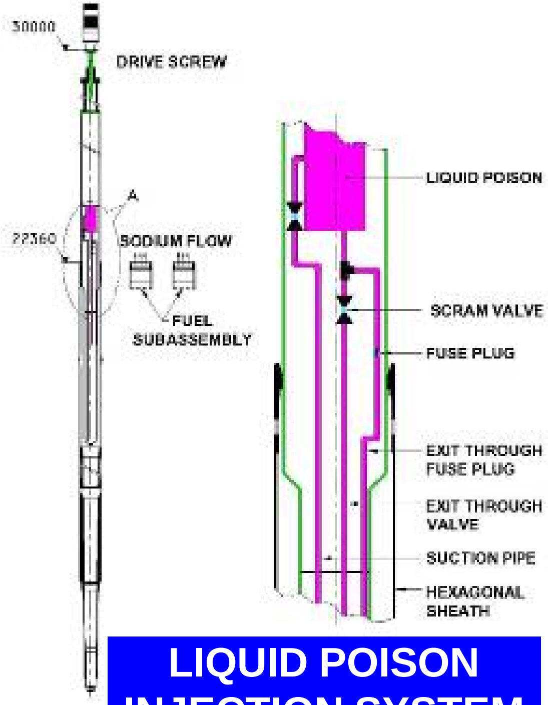
DROP TIME USING ECPS



CSRDM WITH SLD



DSRDM WITH TSM



LIQUID POISON INJECTION SYSTEM

Reliable Drop Time Measurement

Multiple techniques (Eddy Current, Kalman Filter & Accoustics) developed

Safety enhancements

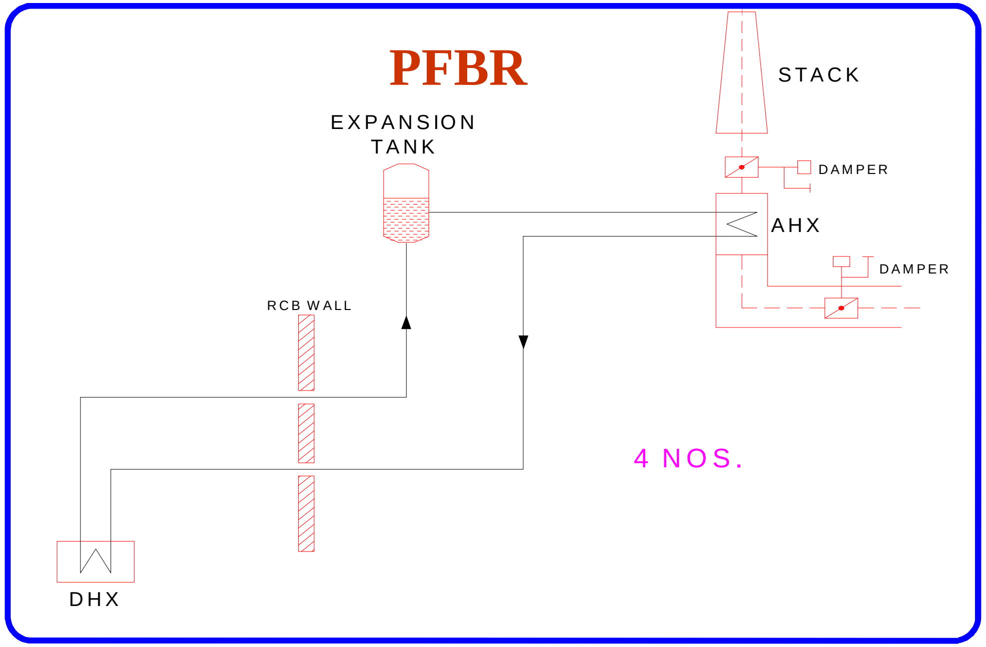
(i) Stroke limiting device in CSRDM to minimise probability of occurrence of inadvertent withdrawal of Control & Safety Rod

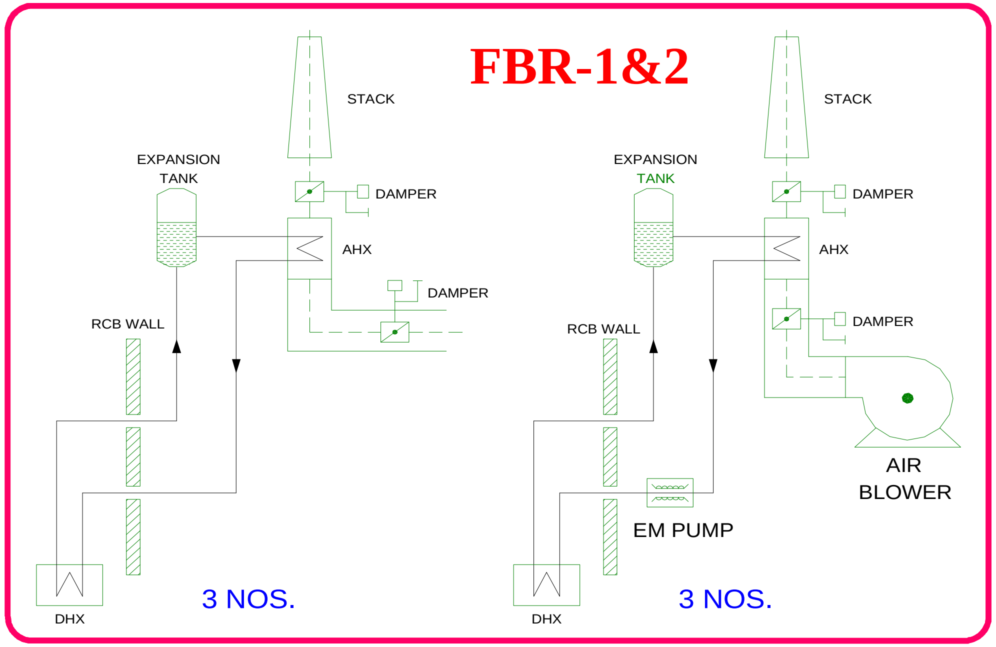
(ii) Temperature Sensitive Electro Magnet in DSRDM to minimize failure of SD system due to instrumentation failure

(iii) Additional Liquid Poisson Injection System

OBJECTIVE : Enhanced reliability by one order of magnitude

Decay Heat Removal Systems





PFBR

4 SGDHR circuits each with a power removal capacity of 8 MWt through natural convection

FBR 1 & 2:

3 SGDHR circuits with mixed convection (2/3 of heat removal under natural convection)

3 SGDHR circuits with a power removal capacity of 6 MWt through natural convection

R&D for FBR safety: Current and Future

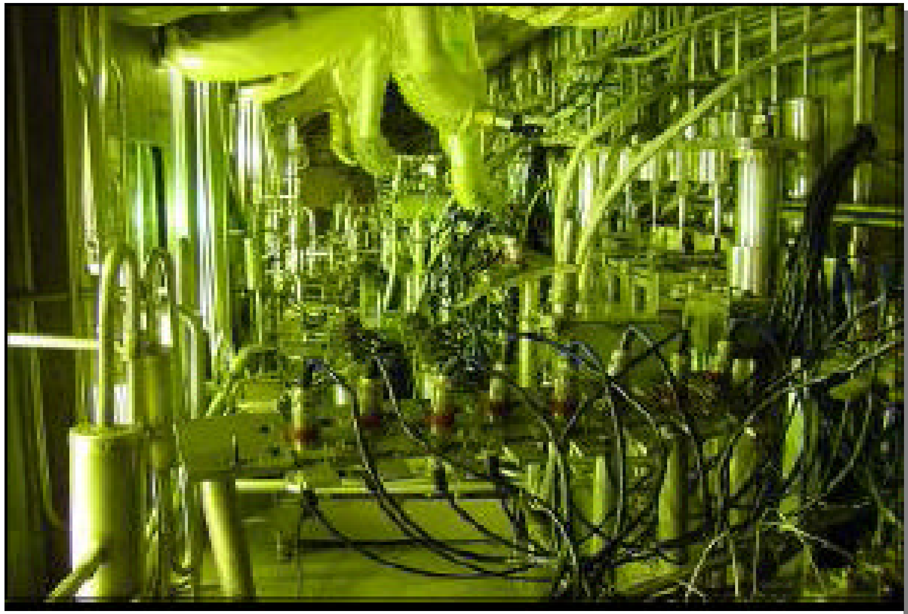
Establish Long-term Coolability of Core Debris

- Molten Fuel Interactions with structures and coolant (SOFI)
- Heat transfer mechanisms of debris settled on core catcher (SASTRA)
- Confirmation of natural convections in the pool and SGDHR circuit (PATH and SASTRA)

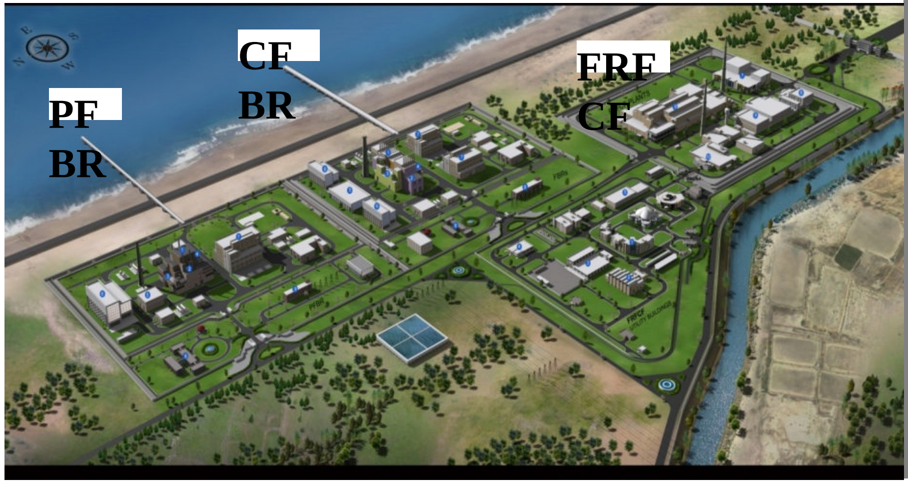
Performance Evaluation of Passive SD Systems

- Stroke limiting device
- Curie point magnet based systems
- Granular B4C based system
- Lithium Poison Injection system

Fast Reactor Fuel Cycle



CORAL FRFCF



- U, Pu mixed carbide fuel used in FBTR: Over 1200 Mark-I fuel pins have reached 155 GWd/t burn-up; Fuel discharged at burn-up upto 150 GWd/t reprocessed in CORAL facility and closure of fuel cycle demonstrated
- Demonstration fuel reprocessing plant to be commissioned in 2014
- Fast Reactor Fuel Cycle Facility with Fuel Fabrication, Reprocessing and Waste Management plants for closing fuel cycle of PFBR